Kohta Ueno

Multifamily Humidity Control Problems: Muggy Mayhem

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Thanking (a few) Mentors-the Technical Knowledge

Joe Lstiburek

John Straube

Andy Åsk

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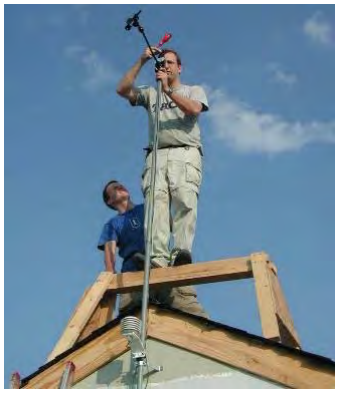
Thanking (a few) Mentors-the Technical Knowledge

Joe “Hoser” Lstiburek



John “Danger” Straube

Andy “Santa” Åsk

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Problem Background and Symptoms

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What We Hear from the Field (The Problem)

- Multifamily buildings, new construction (typical)
- Condensation, staining, and mold on cooling registers, exhausts
- Staining, and mold and on furnishings & clothing
- Ductwork in ceiling cavity: condensation & dripping (sometimes)
- Occupants report high humidity—"cold but clammy"
- Adding dehumidifier in units typically helps
- Owners need a longer-term solution, not a band-aid

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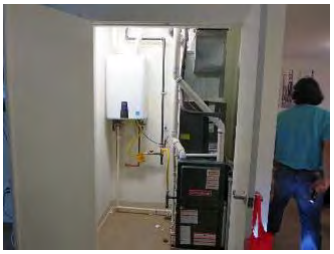
Pennsylvania Example



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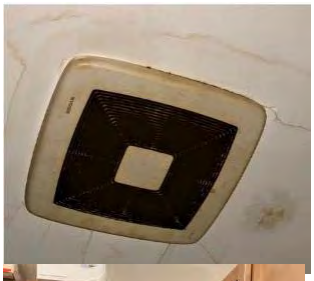
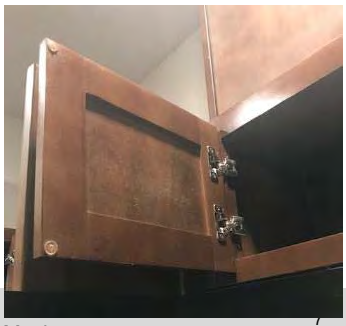
Georgia Example



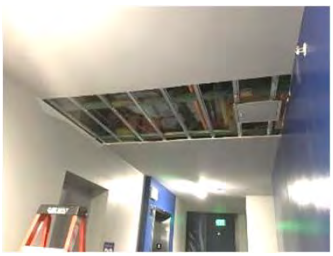


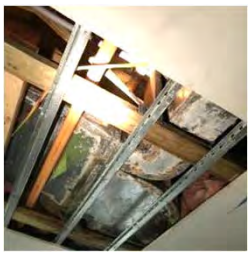
Long Island/NY Example





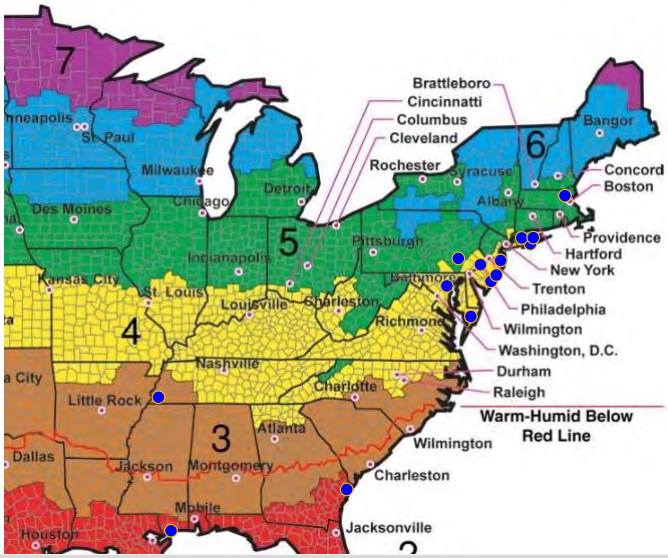

Baltimore MD Example

Where Are These Happening?

- East Coast (4A) dominant
- Some hot-humid (2A, 3A)
- Typically, mid-rise multifamily (also townhomes, hotels, assisted living facilities)
- Typically, new or recent construction/renovation
- Anecdotally, Energy Star or efficient construction ("…this didn't happen on the last job!")



What We're Covering

- Indoor and Outdoor Moisture
- Cooling Sizing: Enclosures & Loads
- Mechanical Ventilation Systems & Multifamily Buildings
- Air Leakage and Humidity
- Mechanical Systems and Dehumidification
- Mechanical Dehumidification Solutions
- Case Studies

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Indoor and Outdoor Moisture

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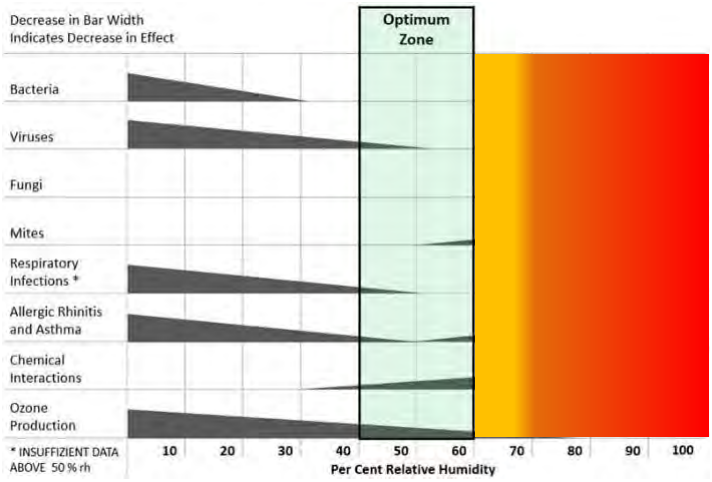
Interior Relative Humidity

- Sterling chart (1986)
- Health and indoor air quality vs. interior humidity
- Keep interior relative humidity below 60% (summertime problem)
- High RHs → mold risks as visible problem/symptom



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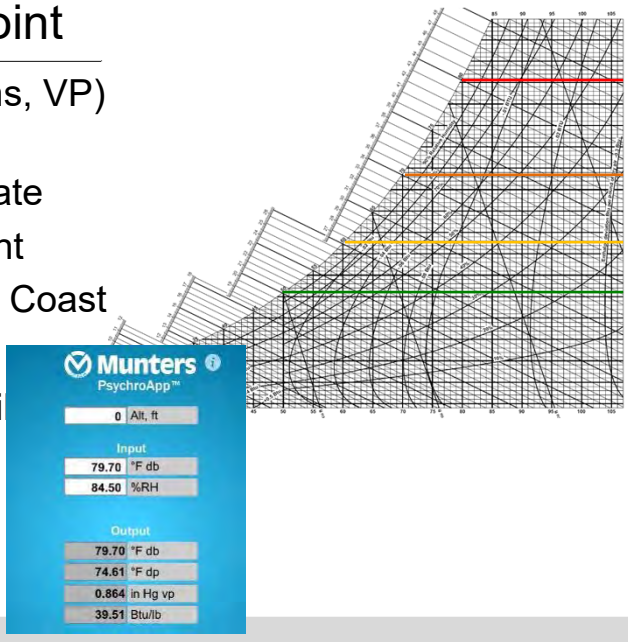
Indoor and Outdoor Dewpoint

- "Thinking in dewpoint" (not grains, VP)
- **50 F DP**: 70 F/50% RH; California & Mediterranean climate
- **60 F DP**: starts to feel unpleasant
- **70 F DP**: peaks of summer East Coast
- **80 F DP**: worst of Florida
- ASHRAE: keep **DP < 60 F** in bui with AC
- PsychroApp calculator app



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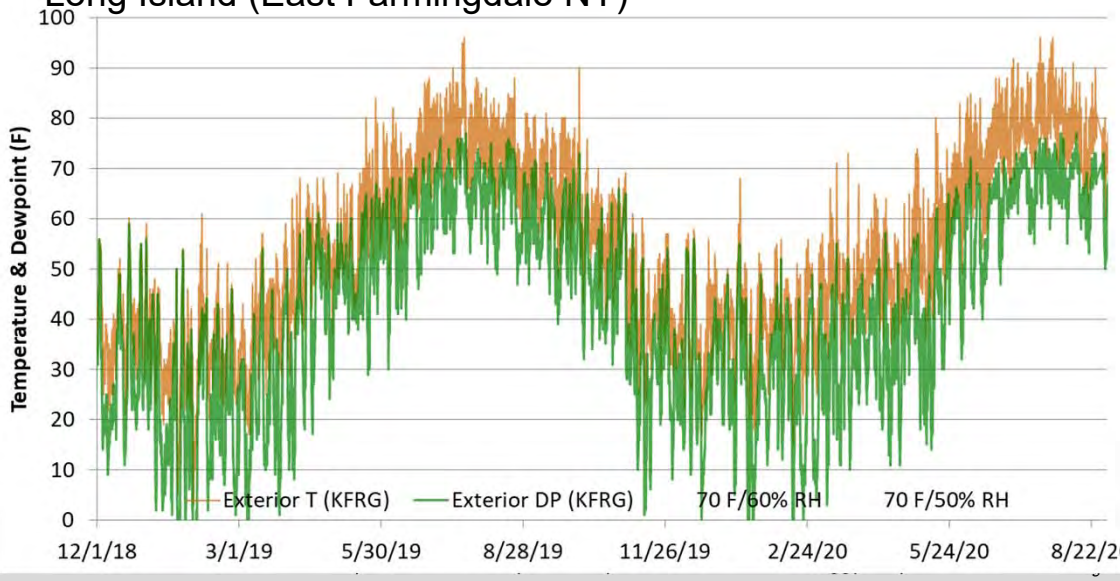
Indoor and Outdoor Dewpoint

- Long Island (East Farmingdale NY)



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Indoor and Outdoor Dewpoint

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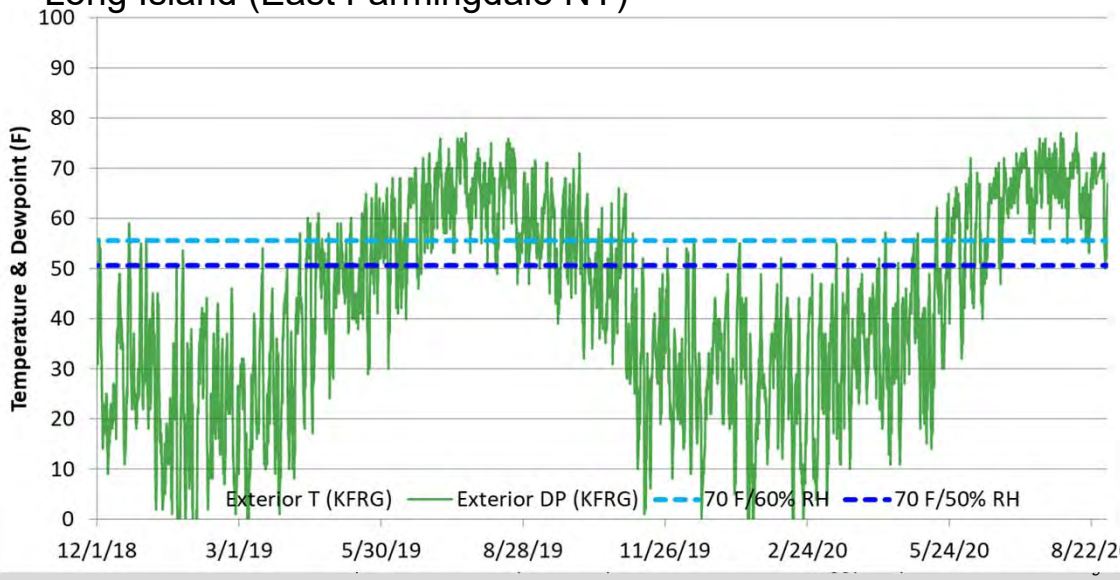

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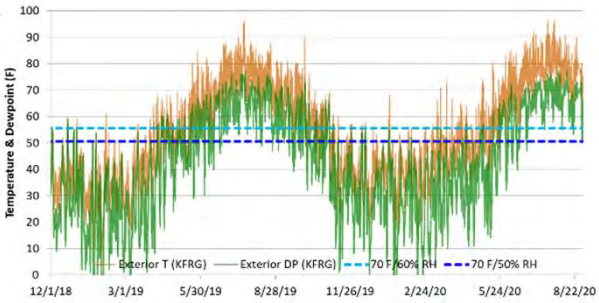
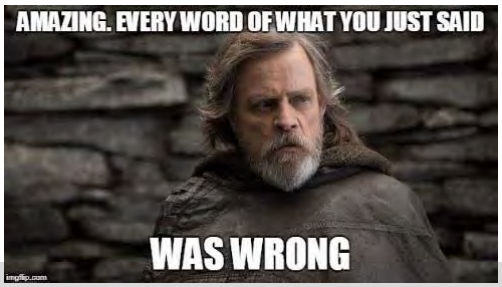
Interior vs. Exterior Moisture

- "You're building too tight, and the moisture's trapped inside!"
- Winter problems: yes
- Summer problems: no
- Summertime humidity problems: ***untreated outside air***
  - Unless massive interior moisture source
- Ventilation/overventilation
- Air leakage
- Poor dehumidification





Cooling Sizing: Enclosures & Loads

Mechanicals Overview

- Cooling is only dehumidification mechanism available (typically)
- HVAC controlled by temperature not humidity (typically)
- “Incidental dehumidification” from cooling operation

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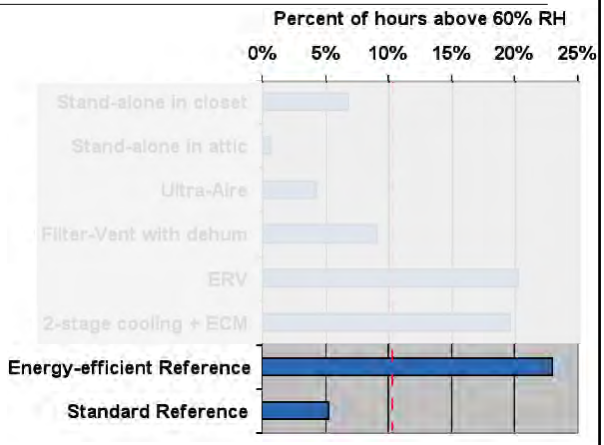
Houston Dehumidification Research (2002)

- Building America project improving single family new construction
- Improved energy efficiency
  - Ducts inside (unvented attic)
  - Glazing from single to double low E
  - Upgraded insulation
  - High efficiency mechanicals
- 5%→23% of hours over 60% RH
- Improved enclosure → less AC runtime → less dehumidification



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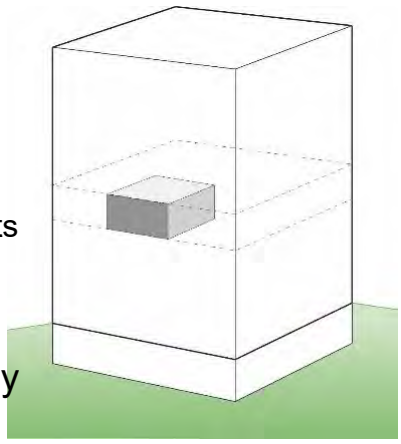
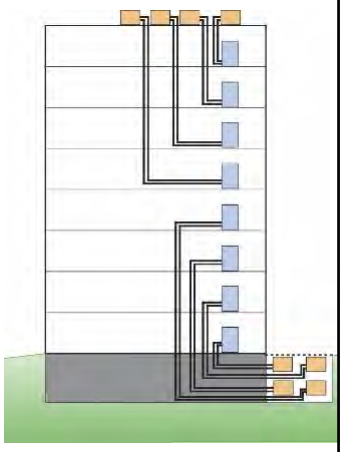
Multifamily Equipment

- Sealed combustion or heat pump air handlers typical (split systems)
- Ductwork in ceiling above unit
- High(er) efficiency equipment generally

Multifamily Building Cooling Loads

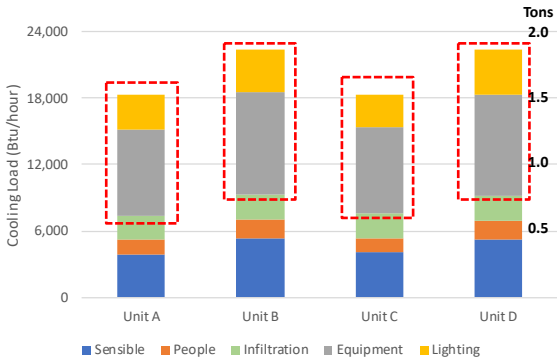
- Some “sides of the cube” have ~zero load
  - Middle, corner, roof units
- Peak design loads-Philly
  - ~7000-9000 Btu/hr per unit
  - Bad assumptions-big impacts
- Installed equipment:
  - 1-½ ton AC (18,000 Btu/hr)
- Oversized x2 on design day (35 hottest hours/year)





Multifamily Building Cooling Loads

- Townhomes and over/under units have problems too! (1000-1300 sf)
- 2 ton ACs at each unit
- Equipment + Lighting adds ~1 ton?!
- Manual J "arbitrary safety factors indefensible"
- Efficient lighting → less waste heat
  - Calcs assume 1000 W @ peak load
- With more reasonable loads: under 1 ton per unit



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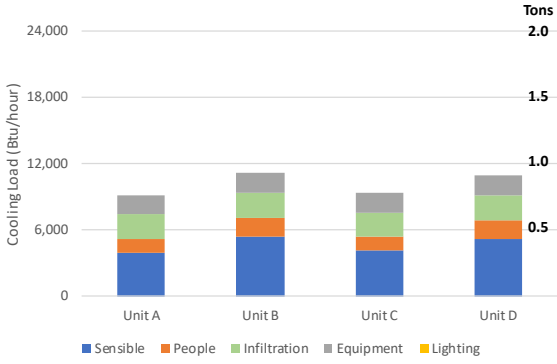

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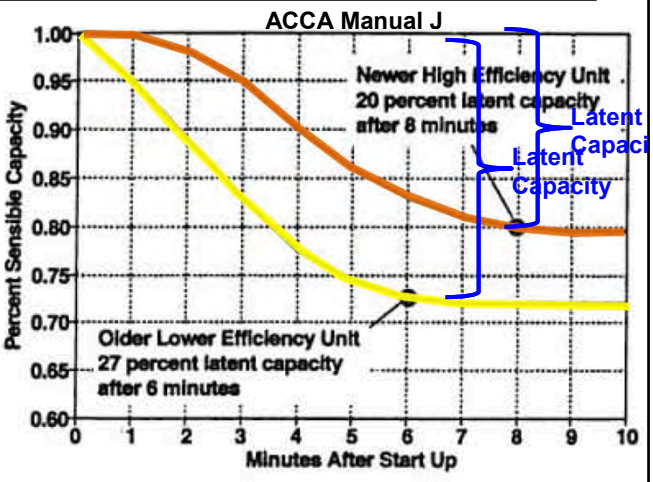
Sensible & Latent Loads

- Sensible = temperature-based load
- Latent = moisture/dehumidification load
- SHR = “sensible heat ratio”
  - SHR = 0.7 = 70% sensible, 30% latent
- AC equipment: ratio of how much ‘incidental dehumidification’ happens when cooling
  - Equipment SHR varies (limited range)
- Building’s SHR (sensible vs. latent loads)
- Sensible load ↓, latent load (ventilation, occupants) stays the same
- “A sensible-latent mismatch between equipment and building loads”

High Efficiency Air Conditioner Units

- “Percent Sensible Capacity” (remainder = latent/moisture)
- Startup = all sensible no latent
- Old ~10 SEER equipment: more latent capacity faster
- Newer high SEER: less latent capacity, longer time
  - Larger coils for higher efficiency
- ***Short cycling due to oversized equipment***



Mechanical Ventilation Systems & Multifamily Buildings

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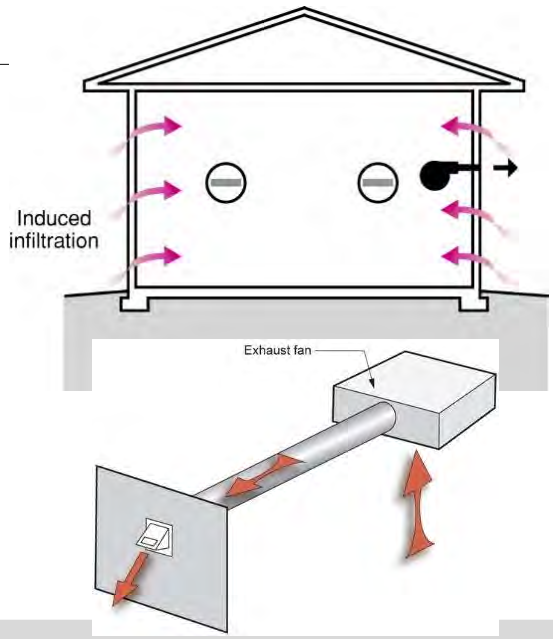
Exhaust-Only Ventilation

- Lowest cost (developer's choice)
- Depressurizes building ("induced infiltration")
- Draws air from wherever leaks are (unknown sources)
- Draws air from crawl spaces, basements, attics, garages…
- In multifamily: air from adjacent units, corridors, shafts…



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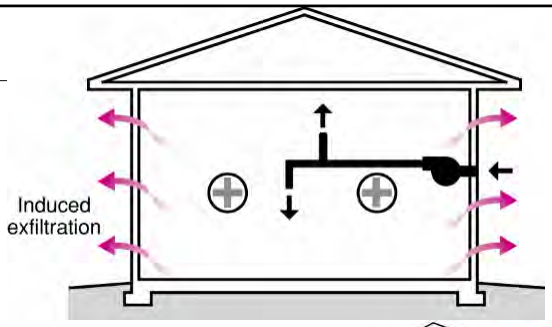
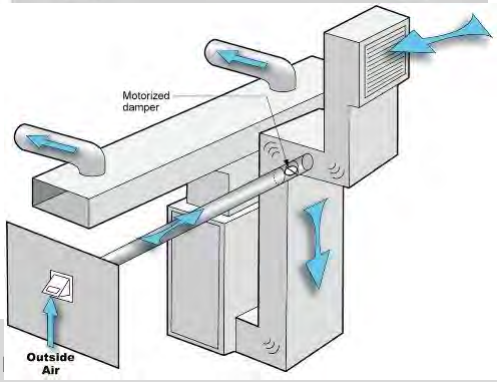
Supply-Only Ventilation

- Pressurizes building ("induced exfiltration")
- Draws air from known source
- Mixing or preheating required for comfort

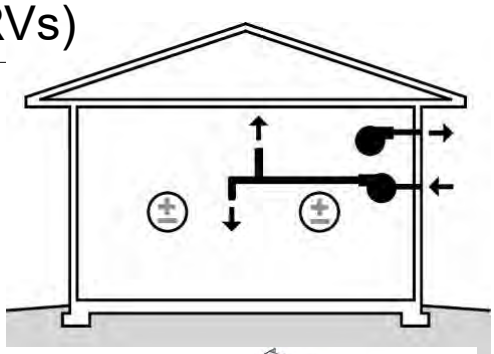
- Central fan integrated ventilation (outside air duct to return, motorized damper)

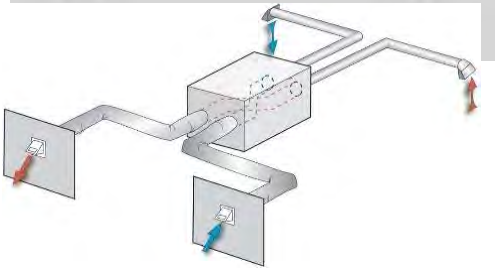




Balanced Ventilation (HRVs & ERVs)

- Building pressure neutral
- Draws air from known source
- Works with tighter construction, multifamily
- Heat recovery → energy performance
- Highest cost





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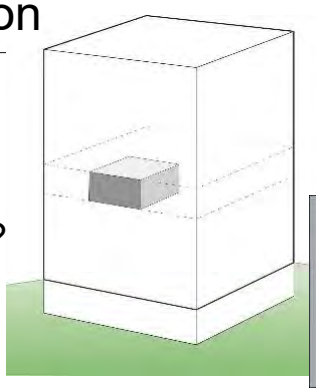
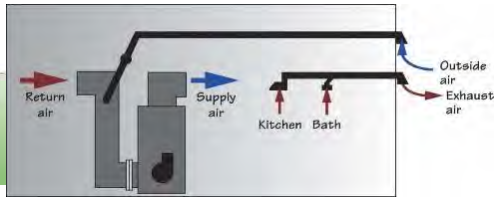
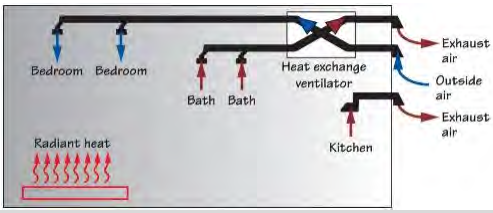
Multifamily Ventilation

- Central unit (rooftop)?
- Individual ventilation systems?
- Floor-by-floor systems?
- CFIS + exhaust
- Balanced systems are recommended approach
- HRV/ERV and independent heating/cooling

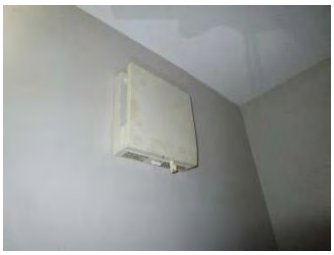






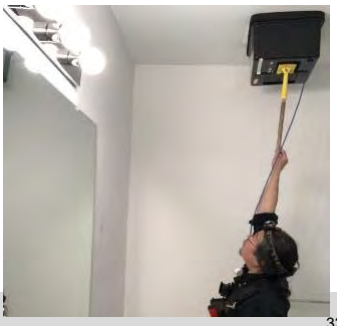
Exhaust-Only Plus Trickle Vents

- "Adding a hole to outdoors"
- Area of hole vs. area of all other leaks
- Unit must be incredibly tight for trickle vent as outside air source
- 100 CFM unit exhaust, 10 CFM flow



Exhaust Airflow Rates

- Energy Star & building code requirements
- Measure airflows-overventilating?
- Current exhaust fans ramp up to target flow
- Two bathrooms per unit w. exhausts
  - Design: one constant, one intermittent/switched
  - Actual: both constant—doubled ventilation rate



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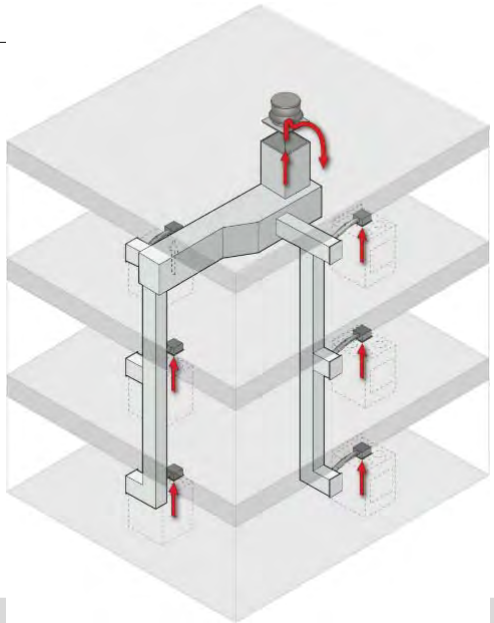
Ventilation Rates

- Old ASHRAE 62.2: 7.5 cfm/occupant + ***0.01*** cfm/sf floor area
- ASHRAE 62.2-2013 7.5 cfm/occupant + ***0.03*** cfm/sf floor area
- 2 BR, 1000 sf = ***33 CFM (old)*** ***vs. 53 CFM (new)***
- Outdoor air = moisture loads
- Over-specified flows to make up for bad distribution
- Pandemic ventilation rate increases?



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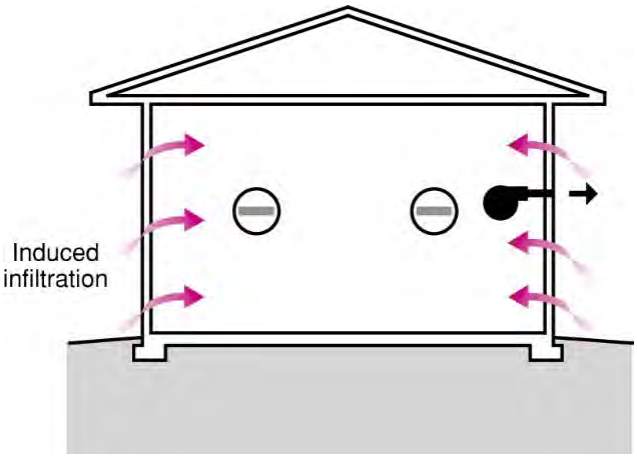
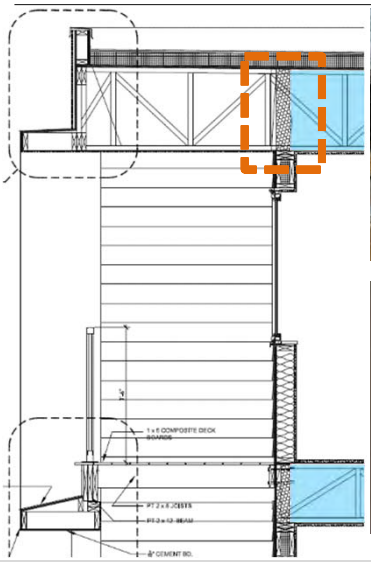
Air Leakage and Humidity

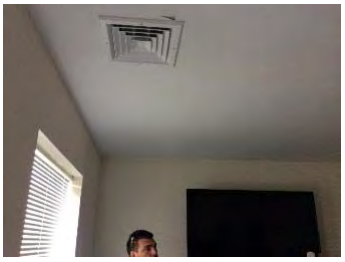
Air Leakage and Humidity

- Outside air → summertime moisture
- Exhaust-only ventilation: makeup air enters at biggest remaining holes
- Energy Star/High Performance: often air leakage testing done...
- Remaining leaks are often tricky or weird problems



Open Web Floor Truss Air Leaks





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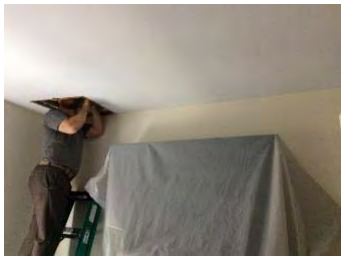
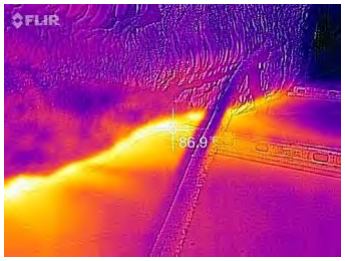
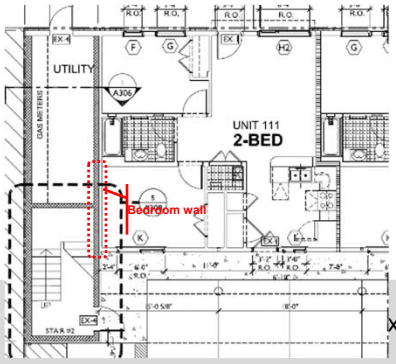
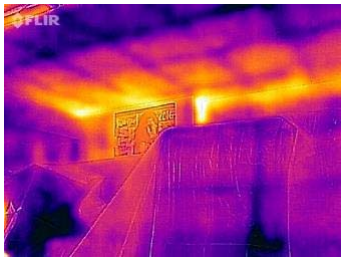


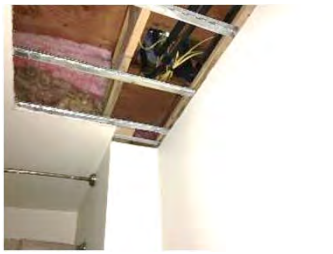
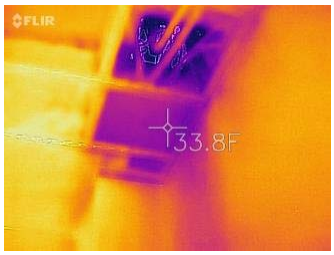


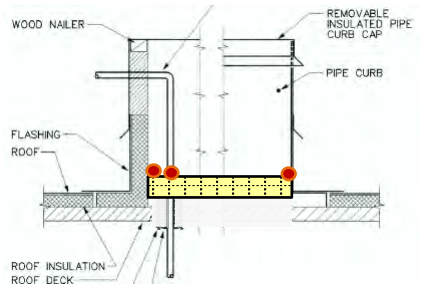




Lineset Roof “Doghouse” Penetrations

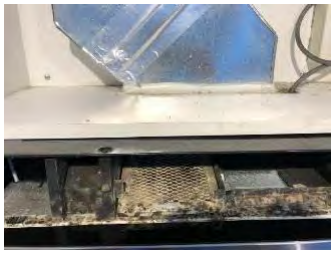




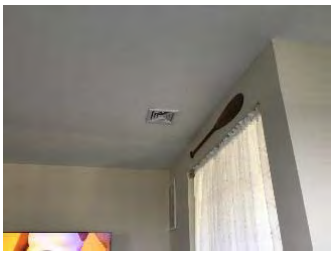
“Intentional Holes” (Microwave Exhaust)

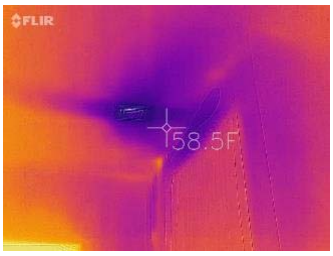




Why the “Halo of Mold”?

- Cold air is driest air
- But when AC turns off…
- Also, uninsulated boot in vented attic dripping





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Mechanical Systems and Dehumidification

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Mechanicals Overview

- Cooling is only dehumidification mechanism available (typically)
- HVAC controlled by temperature not humidity (typically)
- "Incidental dehumidification" from cooling operation
- Problems from underperforming cooling (failing to dehumidify)
- Diagnostic measurements & fixes

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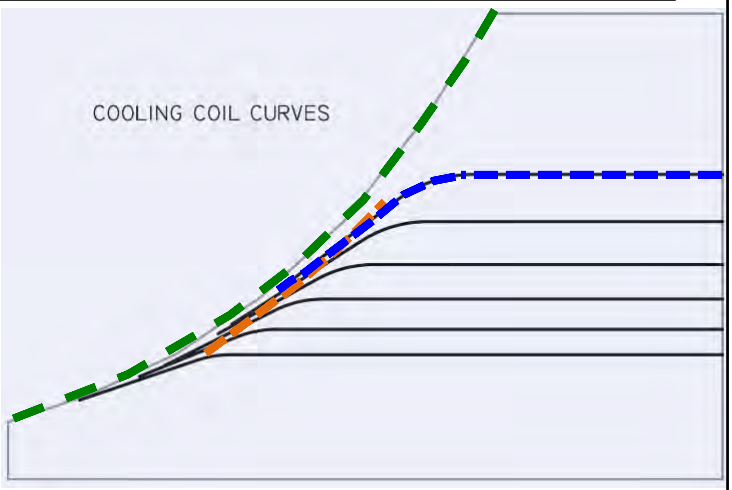
How Do Cooling Systems Work? (Dehumidification)

- Horizontal = temperature
  Vertical = moisture
  Curve = 100% RH
- First "dry cooling"
- Next dehumidification + dry
- Air coming out of cooling coil ~95% RH
- We want ~50 DP air or drier
- ***We need to cool air down to ~50 F or colder to get ~50 DP air***



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Air Handler Temperature/RH

- Diagnosing humidity control problems
- "Split" (return-supply ΔT) indicates performance
- 18-20 F "split" means good dehumidification
- 50 F supply air great
  - 70 F indoors – 20 F split = 50 F
- 60 F supply air = ~60 F dewpoint
  - ***This system can never achieve 50 dewpoint indoors***

Air Handler Temperature/RH

- 18-20 F "split" means good dehumidification
- Also measure supply vs. return dewpoint
  - Direct measurement of moisture removal
- Suspects:
  - Refrigerant charge problems
  - Airflow problems

System	ΔT	ΔDP	ΔT	ΔDP
1	18.0° F	4.0° F		
2	18.0° F	8.0° F		
3	7.0° F	2.0° F		
4				
5				
6	11.0° F	3.0° F		
7	12.0° F	2.0° F		
8	11.0° F	1.0° F		

Air Handler Temperature/RH (PTAC)

- PTAC cooling **ON**/fan on: Δ DP = 13-15F
- PTAC cooling **OFF**/fan on: Δ DP = -2 F
  - PTAC is adding moisture to the room!
- Continuous PTAC fan = terrible dehumidification
- Continuous fan is default PTAC setting

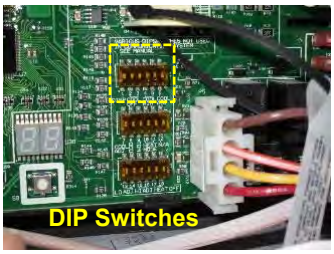
Unit/Condition	ΔT	ΔDP	ΔT	ΔDP
C2-Fan On	2.0° F	-2.0° F		
C2-Cooling On	17.0° F	13.0° F		
D2-Fan On	5.0° F	-2.0° F		
D2-Cooling On	20.0° F	15.0° F		

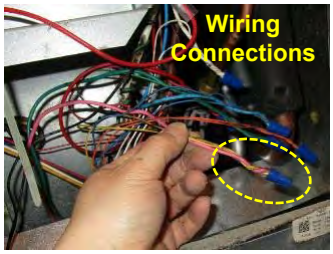
Cooling Airflows and Dehumidification

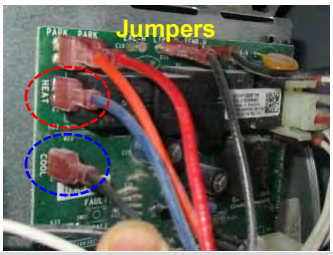
- Flow the air "low and slow over the coil" for greater humidity removal
- "CFM per ton" or airflow per unit of cooling
  - (1 ton = 12,000 Btu/hour)
- 400 CFM/ton: "normal" operating condition
- 450 CFM/ton: **efficiency ↑↑, humidity removal ↓↓**
  - Used in hot dry climates
- 325-350 CFM/ton: **humidity removal ↑↑, efficiency ↓↓**
- ***Removing moisture costs energy***
- Home Innovation/NAHB research: 245 CFM/ton great dehumidification without coil freeze-up

HVAC System Airflow Settings

- DIP switches & jumpers & and taps (oh my!)
- Installers leave at default
- 2 ton (800 CFM) air handler + 1-½ ton outdoor unit = **530 CFM/ton**







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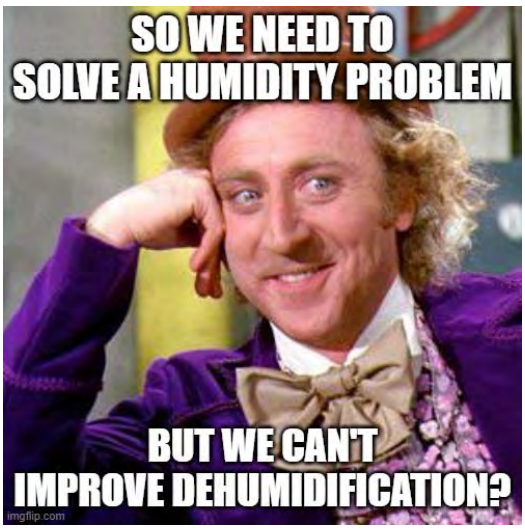
HVAC System Airflow Settings

- "We can't turn down the airflow: colder ducts means more condensation."
- Remember—sweaty ducts are inside conditioned space
- Time for math: $Q = 1.07 \cdot \Delta T \cdot CFM$
- $Q_{before} = Q_{after}$
- From 400 CFM/ton → 350 CFM/ton
- Delivery temperature drops by 2 F assuming not change in latent / moisture removal



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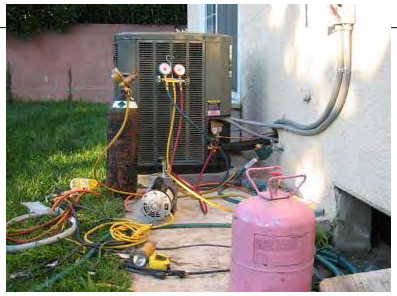
Refrigerant Charge

- AC refrigerant charge – large effect on equipment efficiency, capacity, moisture removal
- Too much or too little = problems
- AC outdoor units “precharged”… for 15 feet of lineset
- Multifamily buildings = longer distances from outdoors to unit



Ductless Heat Pumps (“What About Mini Splits?”)

- Come in smaller sizes
- Modulating good
- BUT still humidity issues
  - Peak load = cold coil, good dehumidification
  - Part load = warm coil, less dehumidification
  - “Dry mode” underwhelming
- Multi-splits/VRFs
  - Don’t modulate the same way as MSHPs
  - Outdoor unit modulation vs. indoor unit sizing limitations

Variable Speed Asian Air Handlers

- Part load conditions: ΔT=9 F (minimal dehumidification)
- Force into “high load” (turn setpoint way down): ΔT=20 F
- Rooftop unit modulates, expansion valve modulates
- “Dry mode” = low fan speed: a bit helpful…. but not much

Occupant Operation of Mechanicals

- Thermostat on-off operation
- Swapping windows open vs. closed up
- Very cold setpoints → colder duct surfaces
  - Delivery air temperature & longer runtimes
- “FAN ON” instead of “FAN AUTO”
  - Turns AC into “re-humidification” system
- Ventilation fans left on 24/7/365

Part-Load Humidity and Dehumidification

- Better enclosures/shells: less cooling load
  - Windows, shading, insulation levels, airtightness
- Less runtime → less dehumidification
  - "Shoulder" seasons often worst
- Oversized cooling equipment → poor dehumidification
  - Two stage/multi speed helps, but…
- High-efficiency HVAC → worse dehumidification
- Adding supplemental dehumidification might be more and more necessary?

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Mechanical Dehumidification Solutions

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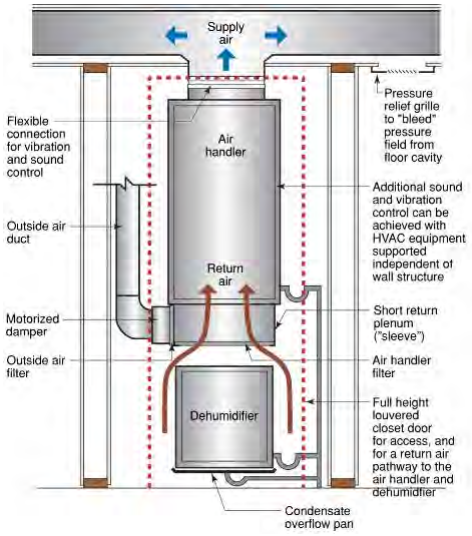
Adding Dehumidification (Closet AHU)



Wall-Mounted Dehumidifier

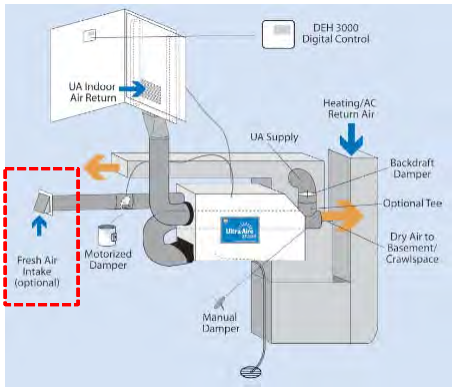
- Power and drain connections required

Front Cover

Internal Components

Ducted Dehumidifier (Integrated with HVAC)

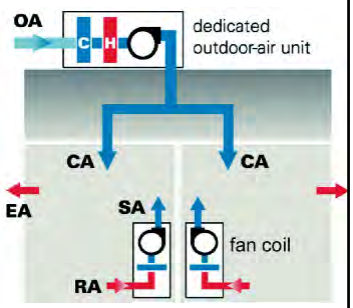
- Ducted high efficiency units
- Corridor dehumidification, “filters” to apartments?
- Dehumidify outside supply air option



Make-Up Air and Dedicated Outside Air

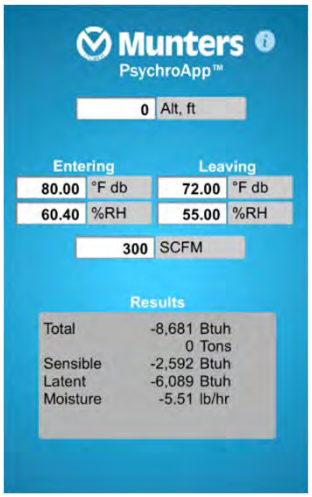
- “MUA” or “DOAS”
- Precondition ventilation supply air, addressing heating, cooling, dehumidification
- Separates heating/cooling of space from ventilation loads
- Supply ventilation @ ***drier*** than interior target

- Capital equipment cost
- Complexity (not for residential-level technicians)



Calculating Humidity Loads

- 65 F DP outside air
  - 80 F/60% RH
- 300 CFM = 5.5 pints/hr = 132 pints/day
- Residential dehumidifier 30-50 pints/day
- Cooling system deals with some moisture—e.g., half?



Calculating Humidity Loads

≈

75 CFM @ 65 F DP

33 pints/day

Case Studies

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Window Replacement

- Hot humid, uninsulated block 1950's construction
- Replaced windows w. vinyl double low-E
- AC remained same
- Mold growth on HVAC, ceiling, floors
- Reduction in load → less AC runtime → less dehumidification

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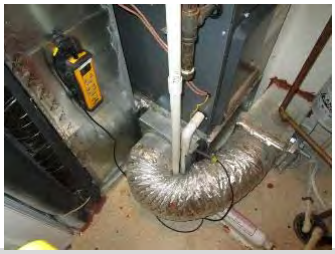
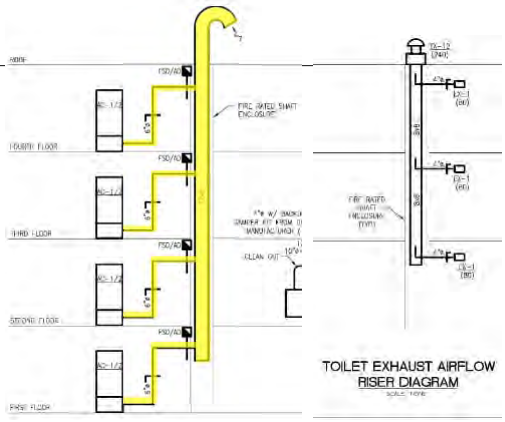
Uncontrolled CFIS Ventilation

- Outside air (OA) duct to return
- Bath exhausts (“semi-balanced”)
- No motorized damper on OA duct
- Peak summer load = draws more OA
- Depressurization → duct sucks OA with air handler off





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All-Exhaust Ventilation & Tight Construction

- ZIP wall sheathing, spray foam roof
- All guest rooms constant exhaust fan operation (lo/hi)
- No make-up air system
- -10 Pascals typical; 3000 CFM of exhaust
- -15 Pascals with kitchen exhaust fan on
- Fireplace no longer drafts

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VRF Space Conditioning

- 70%+ RH in summer
- Good ‘split’/ΔT at heads
- BUT heads running in constant fan mode
- Still oversized
- Setting for fan cycling

Function	Settings	Mode No.	Setting No.	Initial setting (Factory setting) —:Not available									
				4-WAY cassette		Ceiling suspended		Wall mounted	Ceiling concealed			Floor standing	
				PLA-(A)RP-BA(2)	SLZ-KA-VA(L)VAQ	PCA-RP-KAQ	PCA-RP-HAQ	PKA-RP-HA(L)KAL	PEAD-RP-JA(L)Q	PEA-RP-GA(2)	SEZ-KD-VA(L)VAQ	PSA-RP-KA	
Fan speed during the heating thermostat is OFF	Extra low	26	1	●	●	●	●	●	●	● (200/240)	●	●	
	Stop		2										
	Setting fan speed		3							● (402/520)			
Fan speed during the cooling thermostat is OFF	Setting fan speed	27	1	●	●	●	●	●	●	●	●	●	
	Stop		2										

“How Much Exhaust Flow?”

- ΔP ≈ -12 Pa across entire building
- Rooftop unit supply vs. exhaust close to balanced
- Add in all unit exhaust fans 24/7/365

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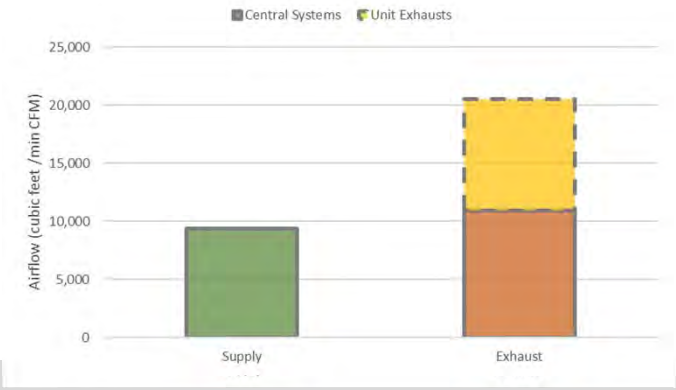
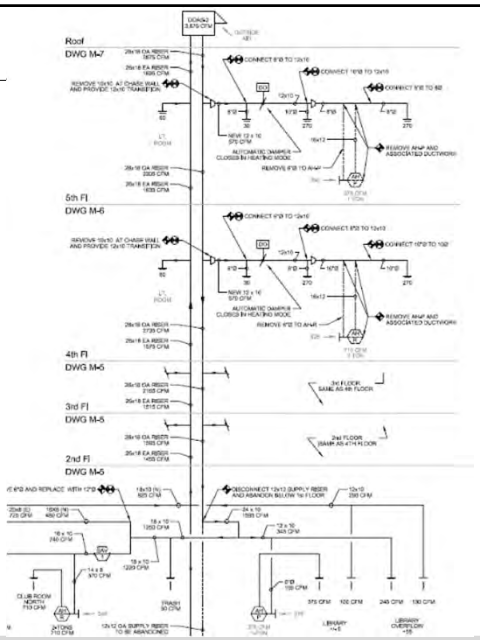


"How Much Exhaust Flow?"

- Reducing exhaust airflows
- Changing exhaust risers to supply
- New rooftop MUA units



Conclusions & Action Items

Pitfalls to Watch Out For

- Untreated outdoor air
  - Ventilation/overventilation (more summer air = more moisture)
  - Uncontrolled air leakage (especially “induced infiltration”)
- Poorly dehumidifying cooling equipment
  - Oversized units—better insulation & windows
  - Poor dehumidification setup (split measurement, CFM/ton, refrigerant charge)
- Occupant behavior
  - On-off operation, swapping windows open vs. closed up, very cold setpoints
- Problems often additive—“perfect storm”
- We used to get away with marginal situations

Recommendations/Action Items

- Keep building good buildings! (with good equipment)
- Pay attention to ventilation rates/flows
  - More airflow, more problems
- Balanced ventilation >> exhaust only; HRV/ERV best
- Specify 350 CFM/ton and verify (AHU settings)
- Remaining air leaks can still cause problems
- Preplan dehumidifier connections?
- If problems occur:
  - Verify list above
  - Field measurement of temperature ‘split’—is AC dehumidifying?
  - Add mechanical dehumidification?

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Questions?

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Document Resources

- Building Science Digest 110: HVAC in Multifamily Buildings
  http://www.buildingscience.com/documents/digests/bsd-110-hvac-in-multifamily-buildings
- Building Science Insight 012: Balancing Act - Exhaust-Only Ventilation Does Not Work
  http://buildingscience.com/documents/building-science-insights/bsi-012-balancing-act-exhaust-only-ventilation-does-not-work
- Information Sheet 611: Balanced Ventilation Systems (HRVs and ERVs)
  http://buildingscience.com/documents/information-sheets/info-611-balanced-ventilation-systems
- Information Sheet 620: Supplemental Humidity Control
  http://buildingscience.com/documents/information-sheets/information-sheet-supplemental-humidity-control
- Information Sheet 607: Refrigeration System Installation and Startup Procedures, and AC Equipment Efficiency
  https://buildingscience.com/documents/information-sheets/refrigeration-system-installation-startup-procedures
- Information Sheet 608: What's the Big Deal About Refrigerant Charge—Why Should the Builder or Homeowner Care?
  https://buildingscience.com/documents/information-sheets/refrigerant-charge
- Research Report 0203: Relative Humidity
  http://www.buildingscience.com/documents/reports/rr-0203-relative-humidity/view
- Building America Report 0219: Residential Dehumidification Systems Research for Hot-Humid Climates
  https://www.buildingscience.com/documents/bareports/ba-0219-residential-dehumidifications-systems-research-hot-humid-climates/view
- Controlling Humidity in Warm Climates, *Journal of Light Construction*, May 2018
  https://www.jlconline.com/how-to/hvac/controlling-humidity-in-warm-climates_o

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